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Abstract

The targets used in the campaign to achieve fusion ignition at the National Ignition Facility (NIF), the world's largest laser, will be some of the most complex and precise ever built. Key to the success of the campaign is repeatable performance of the targets as components of each experiment. We have developed a target design that will achieve the necessary precision and manufacturability, and will also provide the necessary repeatability while retaining experimental flexibility.

1 Introduction

The United States Department of Energy is embarking on a campaign to demonstrate fusion ignition on NIF at Lawrence Livermore National Laboratory in 2010. The ignition target utilizes an indirect drive configuration in which a hohlraum converts the laser light to x-rays that in turn compress an ablator capsule containing a deuterium/tritium (DT) mixture for fuel. Key to the success of the campaign is the repeatable performance of the targets as components of each experiment. This reproducibility is crucial because there are several distinct phases of the overall ignition campaign, called tuning shots, where the results of each phase are used to determine the detailed target specifications in successive experiments. Variability in target parameters, other than those deliberately specified, could severely compromise the entire effort. The novel target design presented here uses precision design techniques and optimizes the fabrication and assembly over a series of difficult requirements.

2 Ignition Target Function

The ignition target is shown schematically in Figure 1. Central to the target is a capsule that is positioned in a 9-millimeter long by 5-millimeter diameter cylinder,

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called a hohlraum. Inside the capsule, the DT fuel is held at a temperature of approximately 18.3 °K. The hohlraum performs two functions: it provides the infrastructure for a precise thermal environment for uniform crystallization of the DT fuel (called "layering") and, at shot time, converts the high intensity laser light to x-rays that uniformly bathe the capsule. When these x-rays hit the capsule, its material ablates outward, driving the DT fuel inward and compressing it to the extreme densities needed to initiate the fusion reaction.

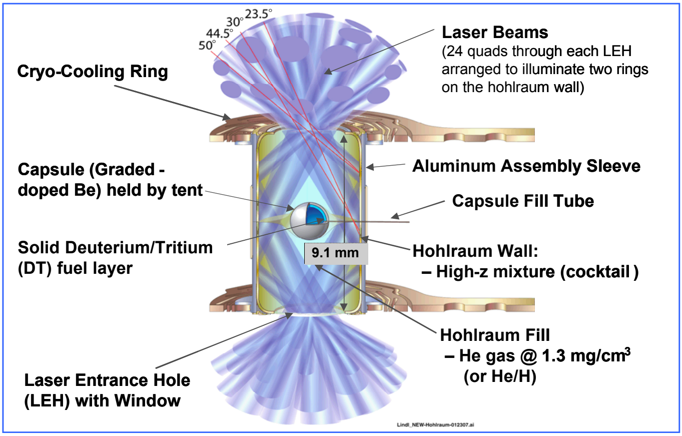

Figure 1. Schematic of the cryogenic igntion target

The target requirements are discussed in the invited paper at this conference by Atherton[1] so they will only be summarized here. The target provides an environment controlled to within ±0.5 mK° so that the DT ice can be uniformly grown on the inner capsule wall. The hohlraum is made of depleted uranium and gold for efficient conversion of ultraviolet photons to x-rays. The capsule must be fabricated from a low atomic mass material to achieve the necessary ablation rate and implosion velocity; the ignition point design utilizes beryllium selectively doped with copper. Of course the target must be cost effective to manufacture since several hundred will be shot during the multiple parameter tuning shots. Finally, during the course of the tuning campaigns, we must be able to change some of the target design parameters with short notice. This required agility is central to an overall strategy in which experimental results of each tuning phase are used to fine tune the designs of subsequent tuning targets. This process will be used throughout the ignition campaign leading up to the ignition target shots themselves – all within a 1- to 2-year timeframe.

3 Thermal Mechanical Package Target Design

Our design concept, called the Thermal Mechanical Package (TMP), is shown in an exploded image in Figure 2. The underlying strategy for the ignition target design is to achieve the separate functions with distinct hardware. To this end, the target is designed with an outer aluminium thermal shell that provides the infrastructure for achieving the ±0.5 mK° thermal control for layering - symmetry about the rotational axis and an axial gradient to mimic a spherically symmetric temperature field. The thermal control is achieved passively for the axisymmetry condition with a bifurcating pattern cut into the silicon heat sinks at each end of the TMP shell. Wound on the thermal shell are two resistance wire heaters that generate a gradient from the heater to the cooling heat sink. With these two heaters, we can 'shim' or shape the first and second modes of the ice layer inside the capsule. By separating the thermal control of the target from the uranium/gold hohlraum, we can implement changes rapidly in the hohlraums and capsules in the tuning campaigns without impacting much of the fabrication and sub-assembly operations. This approach enables an agile response to experimental results of the tuning shots.

Figure 2. Exploded solid model and fabricated hardware of the TMP ignition target

Because of the presence of 330 Torr of helium gas in the hohlraum, convection is a heat transfer mechanism that must be considered. Computational fluid dynamics calculations have shown that the convection effects even without gas flow baffles inside the gas-filled hohlraum are acceptable. The computational method solves the coupled heat and mass transfer equations for the gas flow field in the hohlraum and the thermal profile in the capsule and ice layer for a given set of hohlraum wall heating values. The temperature profile on the inner layer of the ice is then used to predict the ice shape, which is compared over a limited modal spectrum to the required power spectral density.

Inside the thermal shell is a gold/uranium composite hohlraum that performs the function of converting laser light into x-rays. These hohlraums are precision fabricated on diamond turned mandrels with toroidal features to allow assembly with micrometer clearances relative to the inside of the thermal shell. Attached to the partially closed end of the cylinder is the Laser Entrance Hole (LEH) aperture, a critical feature in the performance of the hohlraum. Alignment of the LEHs to the hohlraum is critical for target physics performance but also, when the target is at target chamber center, fiducials on this LEH component are used to align the target to the laser beams in five degrees of freedom.

The final assembly of the target brings two hohlraum half/TMP sub-assemblies together around the capsule, which has a delicate fill tube used to introduce the DT fuel. A key feature of the TMP design is the diagnostic band that aligns the upper and lower halves and provides a platform for locating diagnostic apertures and shields around the waist of the target. After assembly, the capsule is supported only by two 80-nanometer polyimide films (or tents) that are attached to the TMP halves.

The assembly operation is performed with a collection of manual and motor driven commercial stages. More importantly, the metrology for assembly is provided by a commercial optical coordinate measuring machine (CMM). This CMM allows precision image analysis and probing to obtain metrology data such as the capsule to hohlraum relationship and location of the LEH apertures.

4 Conclusion

The fabrication of targets for the campaign to achieve ignition on NIF will be challenging in many ways. The target design concept we've adopted for the ignition campaign establishes a platform that enables rapid response to desired changes in the target parameters. This TMP design provides agility while simultaneously achieving the needed reproducibility, precision and manufacturability.

References:

[1] Atherton, L.J., Moses, E.I., Carlisle, K., Kilkenny, J., *The Ignition Target for the National Ignition Facility*, EUSPEN Conference 2007